CLASSIFICATION OF RISK FACTORS ASSOCIATED WITH MINE CLOSURE

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Abstract

The issues involved in mine closure are usually complex and the risks significant. Although environmental risks are paramount, other issues such as the safety, community, legal, fiscal and technical factors need to be taken into account. This paper describes a simple empirical model based on the concept of the Closure Risk Factor that will enable decision-makers to analyse the mine closure risks at any site regardless of the complexity of the issues and the scale, scope and location of the operation. The model enables all the issues to be captured, and their individual and collective risk quantified. A number of case studies in Australia and the Pacific are presented illustrating the usefulness of the model.

INTRODUCTION

Mine closure has increasingly become the focus of mining companies, governments, non-government organisations (NGOs) and other stakeholders and is destined to be the big mining issue of the new millennium. The issues involved in mine closure are usually complex and the risks significant. In the Australian context, the focus of industry and government has, understandably, predominantly been on environmental issues. In other locations such as the Pacific Rim, social and community issues are prominent. Safety and health issues are pre-eminent in some other countries while legal, economic and technical issues such as resource sterilisation are rarely considered. Many of these issues, if not managed appropriately, can result in unacceptable outcomes for the company, the wider mining industry, government and other stakeholders.

It has been apparent for some time that operators and regulators would benefit by a simple model to assist decision-makers to analyse the mine closure risk at any site, regardless of the complexity of the issues and the scale, scope and location of the operation. This paper describes such a model which allows all the issues to be captured and their individual and collective risk quantified.

The model, which is based on the new concept of the Closure Risk Factor,

- addresses closure issues in a structured, systematic manner
- is designed to aid decision making by all those involved in the mine closure process
- will highlight the major closure issues and risks, allowing management and the regulator to concentrate resources appropriately
- allows the relative importance of each of the risks to be determined both qualitatively and quantitatively
- facilitates comparisons between sites

PREVIOUS RESEARCH

Mine closure has become a major issue in the Australian mining industry in the past few years and its importance continues to increase. Conferences and workshops are now focusing on it as a theme (ACMER 1998,1999). The 2001 Minerals Council of Australia (MCA) Environmental Workshop will have Mine Closure as its focus. Much of the research undertaken has been, understandably, of a practical nature and the literature mainly consists of case studies. There have been few papers devoted to mine closure theory. The author produced a paper on the principles of whole of life decommissioning for the Australian and New Zealand Minerals and Energy Council (ANZMEC) based on the continuous improvement model of planning, implementation, evaluation and review (Laurence 1998). ANZMEC and the Minerals Council later produced a "Strategic Framework for Mine Closure" in 2000, a document containing a broad set of concepts and principles to provide the framework for the more specific guidelines to be developed by industry and government (ANZMEC/MCA 2000).

The focus of the Australian literature on mine closure has been on environmental factors. The Strategic Framework for Mine Closure for example states, "at issue is the development of an effective and efficient approach to the funding of closure that enables mine rehabilitation and other environmental objectives to be achieved…". It also mentions that "the objective of mine closure is to prevent or minimise adverse long-term environmental impacts, and to create a self-sustaining natural ecosystem or alternate land use …”. This paper argues that there is a danger in neglecting other issues involved in mine closure.

Most advances in research internationally have been in the area of abandoned or orphaned mines. For example, the Ontario Ministry of Northern Development and Mines supported the work of researchers (Bolger et al 1993) in developing a system for rating hazards at the many abandoned mine sites in that province. The authors developed a classification system that allowed decision makers to compare different sites and to set priorities based on a set of complex factors. The technique allowed both technical and socio-economic factors to be taken into account using the mathematical technique of multicriteria analysis. An important issue was to find the relative importance or weight of each factor. This research focused almost entirely on the hazardous nature of the abandoned mine including the risk to a person by falling into a stope or open pit, the failure of a dam, or entering a confined space and being asphyxiated. Far less emphasis was placed on environmental issues, in contrast to Australian studies of abandoned mines.

This attention to the safety aspect of closed mines is further developed in a paper by Carter et al, 1995, which described a coordinated approach to the remediation of old mines in the Cobalt region of Ontario. The workings were located underneath highways and commercial and residential buildings and consequently the public risk issue was paramount. A matrix was developed to assist in the prioritisation of remedial works.

INTRODUCING THE CLOSURE RISK FACTOR (C_{RF})

As far as risk management is concerned, mine closure should be treated like any of the other significant stages in a mine's life cycle including exploration, development and then to operations. In each stage, the significant risks have to be managed to ensure the threats to the business will be minimised or eliminated.

The Closure Risk Factor (C_{RF}) is simply a qualitative and quantitative measure that captures the various significant risk components of mine closure. These components can be broadly divided into environmental risks (R_E), safety and health risks (R_{SH}), community and social risks (R_C), final land use risks (R_{LU}), legal and financial risks (R_{LF}) and technical risks (R_T). The Closure Risk Factor is simply the sum of these individual risks. The relationship can be expressed by a simple linear equation:

$$C_{RF} = \Sigma (R_E + R_{SH} + R_C + R_{LU} + R_{LF} + R_T)$$

The CRF allows the closure risks at each mine site to be broken down into as many individual components as considered appropriate by the decision-maker. For example, some of the "non-negotiable" outcomes that a mine manager in consultation with corporate office may wish to achieve include that:

- environmental objectives are achieved in line with best practice and the company's policies and guidelines

- sufficient funds are available to cover closure
- employee entitlements are protected
- the right personnel are in place to manage and implement the closure process
- the community is positive about the process
- resource extraction has taken place in line with the economic model so as to provide optimum benefit for shareholders
- public safety issues will be addressed, and
- the company will be released from liability on the site as soon as possible after operations (and cash flows) cease.

The regulator such as a State Department of Mines and Energy may require that:

- there is sufficient security to enable final rehabilitation and closure to be carried out
- the site will not be added to the list of orphaned or abandoned mines to be rehabilitated at public expense
- the resource has been utilised for optimum benefit for the community
- it will not be embarrassed or “caught out” by releasing securities back to the companies too early, and
- public safety issues are addressed.

Similarly, if a company were purchasing a mining property it would no doubt be interested in ensuring that the purchase price reflects the mine closure risk.

CLOSURE RISKS

The above primary risk classification can be further segmented into ever increasing detail until a complete picture of the risk exposure of the mine is achieved. To assist operators and regulators, the author has compiled a check list of the principal issues and risks that need to be assessed. This check list is based on extensive experience gained from mines throughout Australia and from mines in several other countries. It should be stressed that this classification is meant to be a guide and is not intended to be fully inclusive of all the issues involved at every mine site. Due to the dynamic and diverse nature of the industry, new issues will appear from time to time. Each mine will have a unique classification.

Environmental Risk (R_E)

- Water
    - Surface waters
        - Sedimentation
        - Chemical pollution
        - Drainage
        - AMD/heavy metals
        - Salinity
    - Ground water
        - Contamination

        - Drawdown
    - Environmental values (downstream use)
        - Agriculture
        - Drinking
        - Ecosystem
    - Monitoring
- Air
    - Gas
        - Greenhouse
        - Others including roasting
    - Dust
        - Tailings
        - Stockpiles
        - Rehabilitated areas
- Land systems
    - Visual amenity
        - Close to population centre or main roads
        - Remote
    - Infrastructure
        - Buildings, equipment, camps
        - Roads
        - Stockpiles, dumps, dams, sumps
        - Borrow pits

- Soils
    - Contaminated?
    - Topsoil availability/suitability
    - Erosion potential
- Reshaping/earthworks
- Flora reestablishment
    - Simple
    - Complex
    - Rare/significant
- Fauna reestablishment
    - Terrestrial
    - Avian
    - Aquatic
- Voids
    - Open
    - Backfill
- Subsidence
- Exploration
- Management/monitoring

- Wastes
  - Dumps
    - Reshaping
    - Covers

    - AMD
    - Topography
    - Seismicity
    - Climate
  - Tailings
    - Reshaping
    - Covers
    - AMD
    - Toxicity
    - Stability
    - Landbased
    - Riverine
    - Submarine
    - Radiation
  - Hazardous
    - Chemicals including cyanide
    - Fuels, lubricants
  - Other
    - Sanitation
    - Tyres, machinery etc
    - Garbage
  - Heritage
    - Indigenous

        - Non-indigenous

Safety and Health Risk (R_{SH})

- Openings
    - Shafts, raises, winzes
    - Adits, drifts
    - Open pits
        - Backfill
        - Fencing
        - Bunding
        - Reducing batters
    - Trenches, costeans, drill holes
    - Dewatering of above
- Subsidence
    - Coal or mineral extraction
    - Crown pillar collapse
    - Caving
- Infrastructure
    - Buildings, equipment
- Security
    - Increased security
        - Theft
        - Unauthorised access

- Emergency response preparedness
- Radiation source disposal

Community and Social Risk (R_C)

- Employees
    - Provision for entitlements
    - Retraining, relocation
    - Workers compensation claims
- Management
    - Improved communication
    - Safety awareness – increase in injuries as closure approaches
    - Keeping team together particularly key personnel
    - Contractors
        - Can be used to soften the blow of retrenching employees
        - Potential for cost blow outs
- Unions/employee representatives
- Landowners
    - Indigenous
    - Non-indigenous
- Affected residents
- New settlers
- Local Government
- General community impact

- Local
    - Fly-in, fly-out or mining town
    - One company town?
    - Isolation
    - Mining tradition in area
    - High local unemployment
    - Single industry town
    - Residential property value impact
    - Impact on family values
    - Diversification or decline
    - Return to subsistence?
    - Health issues – alcohol etc
- Regional
- National
- International

Final Land Use Risk (R_{LU})

- High value ($/ha or conservation values)
    - Premium agricultural land
    - Industrial/commercial/residential
    - National park/heritage
- Medium value
    - Return to pre-existing ecosystem

    - Forest
    - Grazing
- Low value
    - Extensively altered site
    - Arid

Legal and Financial Risk (R_{LF})

- Government
    - Regulatory compliance
    - Title
        - Retain
        - Sell
        - Relinquish
    - Security/bond
        - Large
        - Small
    - Documentation
- Creditors
    - Employees
    - Contractors
    - Businesses
    - Government
        - Taxes

            - Royalties

- Provisioning for rehabilitation
    - Provision made
    - No provision
- Salvage
- Potential for adverse publicity and impact on business

Technical Risk (R_T)

- Closure plan
    - Plan exists and up to date
    - Plan not up to date
- Rehabilitation progress against plan
- Closure team
    - Management
    - Environmental
    - Planning
    - Electrical/mechanical/financial
- Resource/reserves
    - Exhausted
    - Not exhausted
        - Accessible for future extraction
        - Potential for new reserves
        - Sterilised

ASSESSING THE RELATIVE IMPORTANCE OF THE RISKS

The power in using this classification system is achieved by applying a weighting factor or score to each level of risk. The weighting is necessarily subjective and depends on the experience of the decision maker and his/her familiarity with the issues. To overcome the subjectivity bias, the analysis should be carried out by a team which is familiar with one or more areas under analysis. For example, if a mining company is assessing the closure risk, the mine manager, environmental coordinator, mine planning engineer, mine geologist, community liaison officer and a representative from corporate office might be involved in the exercise.

If, on the other hand, the closure risk of a mine site is being assessed by the Department of Mines and Energy or equivalent, then a team exercise should involve Departmental environmental scientists, mining engineers and geologists.

ESTIMATING THE CLOSURE RISK FACTOR

The Closure Risk Factor can be estimated by using the above list in a simple matrix approach as shown in Table 1. One advantage of using this approach is that by dividing the issues or risks into as much detail as required, *all* factors or issues that influence closure can be captured. The process will be best approached using a formal or informal, team-based, risk assessment methodology. As in a formal risk assessment, the team should be composed of all those who have a role to play in the mine closure process including the environmental team, the mine manager, mine production personnel, mine planners, community liaison, OHS, geology and metallurgy.

The first step in estimating the closure risk factor is to list and assign a weighting to each of the major issues. Clearly, this will be a site-specific process. For the purposes of the model, it is assumed that a neutral weighting of 1.0 should be assigned to those primary issues considered to be of minor importance or have minimal risks, with a weighting of 2.0 for the extreme risks.

For example, at a particular mine it may be determined by the analytical team that the major risk ratings are:

- environment = 1.8
- community = 1.7
- safety = 1.4
- final land use = 1.5
- legal/financial = 1.2
- technical = 1.0.

The second step is to list and weight the significance of the secondary issues. For example, if we consider the environment, it may be that water is the most significant followed by surface, wastes and air, at 1.5, 1.3, 1.2 and 1.1 respectively.

The final step is to identify and rate the specific or lower order risks and for this prototype model, the issues have been rated out of a maximum of 10. For example, the water issues may be;

- AMD potential = 10
- potential for cyanide pollution = 6

The surface issues might be:

- erosion (highly dispersible soils) = 8
- aesthetics (visibility to public) = 9
- threat to endangered bird species = 7

Waste issues may be

- tailings = 7
- waste dump = 10
- tyres and domestic waste = 4

Dust issues could be:

- dust from tailings = 8

Therefore the risk factor for the environmental component is:

R_E = weighting environment x [weighting water x (specific water issues scores) + weighting surface x (specific surface issues scores) + weighting wastes x (specific wastes issues scores) + weighting air x (specific air issues scores)].

= 1.8 *[1.5 (10+6) +1.3 (8+9+7) + 1.2 (7+10+4) + 1.1 (8)]

= 161

A similar process is used to calculate R_{SH} , R_C, R_{LU}, R_{LF} and R_T.

It should be noted that negative numbers could signify a positive initiative by the company to overcome risks, for example, monitoring of water quality. Another example is an open pit void that will be used by a local council as a landfill. This will result in a lower overall closure risk factor.

The Closure Risk Factor is simply the summation of these components, ie

$$\mathbf{C_{RF} = \Sigma (R_E + R_{SH} + R_C + R_{LU} + R_{LF} + R_T)}$$

CASE STUDIES

7.1 Case Study 1 - Uranium Mine on Aboriginal Land surrounded by World Heritage National Park

1.1 Primary issue weighting

Environmental (R_E)	1.8
Safety and Health (R_{SH})	1.4
Community and Social (R_C)	1.8
Final Land Use (R_{LU})	1.6
Legal and Financial (R_{LF})	1.5
Technical (R_T)	1.3

1.2 Risk factor evaluation

Environmental (R_E)

- Water (weighting = 1.9)
  - Environmental value (downstream use) (weighting = 1.1)
    - Potable/domestic (10 points)
    - Aquatic (10)
  - radiation/heavy metals (weighting = 1.4) (10 points)
  - Sedimentation (w=1) (s=3)
  - Monitoring (w=1.3) (s=-6)
- Air (weighting 1.5)

- Gas (1.6)
    - Radon (7)
- Dust (1.7)
    - Radioactive (9)

- Land systems (weighting 1.8)
    - Aesthetics (w=1.9)
        - close to World Heritage Kakadu Park (s=10)
    - Infrastructure (w=1.5)
        - Buildings, equipment (2)
        - Roads (3)
    - Revegetation (w=1.6)
        - Relatively simple (3)
    - Re-establishing fauna (w=1.1)
        - Terrestrial (3)
        - Aquatic (8)
    - Voids (1.7)
        - Backfilled (2)
    - Monitoring (1.3)
        - Due diligence (-3)
- Wastes (weighting 1.6)
    - Dumps (w=1.3)
        - Reshaping (8)
    - Tailings (w=1.7)

            - Reshaping (10)
    - Hazardous (1.8)
        - Chemicals (5)
        - Fuels, lubricants (4)
    - Domestic (3)

Safety and Health (R_{SH})

- Openings (w=1.5)
    - Open pits (w=1.8)
        - Hazard to humans/fauna (5)
    - Trenches, costeans, drill holes (1.3)
        - Hazard to humans/fauna (5)
- Infrastructure (1.0)
    - Buildings, equipment (1.3)
        - Hazard to humans (5)
- Security (1.4)
    - Threat of sabotage etc (8)

Community and Social (R_C)

- Employees (1.1)
    - Provision for entitlements (3)
    - Retraining, relocation (2)
- Unions (1.6)

    - Health and other concerns (1.7)
        - Radiation exposure (9)
- Landowners (2.0)
    - Indigenous (2.0)
        - Hostility to mine (10)
- Community impact (1.9)
    - Local community impact (1.9)
        - Indigenous, tourism (8)
    - Regional community impact (1.7)
        - Tourism, jobs (7)
    - National community impact (1.6)
        - Export income (9)
    - International community impact (1.5)
        - Nuclear fuel cycle debate (7)

Final Land Use (R_{LU})

- High value (2)
    - National park (1.8)
        - World heritage (10)

Legal and Financial (R_{LF})

- Government (1.9)
    - Title (1.7)

        - Retain (8)
    - Security/bond (1.9)
        - Large (9)
- Creditors (1.7)
    - Employees (1.7)
        - Entitlements (7)
    - Contractors (1.1)
        - Fees (5)
    - Businesses (1.2)
        - Services (4)
    - Government (1.3)
        - Taxes owing (6)
- Provisioning for rehabilitation (2)
    - Provision made (1)
        - Lower liability (-9)
- Adverse publicity (1.8)
    - Protests (1.8)
        - Effect on corporate image (8)

Technical (R_T)

- Closure plan (1.6)
    - Plan up to date (1)
        - Facilitate rehabilitation (-8)

- Rehab progress (1.5)
    - Good progress (1)
        - Reduce liability (-9)
- Closure team (1.4)
    - Management in place(1.4)
        - Essential for good outcome (-4)
    - Environmental team (1.6)
        - Essential for good outcome (-8)
- Resource/reserves (1.7)
    - Exhausted (1.7)
        - Benefits to all stakeholders (-7)

The Closure Risk Factor $\mathbf{C_{RF} = \Sigma (R_E + R_{SH} + R_C + R_{LU} + R_{LF} + R_T)}$ where R_E = 537.0; R_{SH} = 57.3; R_C = 303.8; R_{LU} = 64.0; R_{LF} = 175.9; R_T = -94.0 and therefore, $\mathbf{C_{RF} = 1044.0}$ as shown in table 2.

Therefore, according to the empirical classification in table 5, the closure issues at this uranium mine are complex and the closure risk very high. Accordingly, the company, the government and the relevant stakeholders need to very aware of the issues as the mine life comes to an end to ensure that optimum outcomes are obtained.

It is clear from the analysis that environmental factors are the major issue (with a risk factor of 537), but community issues are also extremely significant (at 304). It can be seen that the technical risks are in fact negative, indicating that the mine has a good handle on closure issues with an up to date closure plan, good progress is being made on rehabilitation and a good closure team is in place.

7.2 Case Study 2 – Small Scale Extractive Operation

Table 3 illustrates a similar exercise for a small extractive pit for sand and gravel, situated close to a major urban centre. In this case, R_E = 122.6; R_{SH} = 28.4; R_C = 45.1; R_{LU} = -5.2; R_{LF} = 48.0; R_T = 12.1. Thus the **C_{RF} = 251.0.**

In this case, and according to Table 5, the closure risk is minor. Due to the small scale of the operation, many of the issues have been given a minimum weighting of 1.0. Environmental factors are of relative importance but not on the scale of the previous example. Safety and health issues and legal/financial issues are also proportionally more significant. The land use issues are negative reflecting the value of the land after mining for an alternative productive use.

7.3 Case Study 3 – Open Pit Porphyry Copper Mine in the Pacific Rim

Table 4 illustrates the closure risks for a large scale, open cut copper and gold mine in the Pacific region. It can be seen that the issues are very complex and the closure risk factor extreme. Environmental and community risks are of such a magnitude that they pose a significant threat to not only the mine but the parent company as well.

In this case, R_E = 1237.2; R_{SH} = 106.7; R_C = 589.6; R_{LU} = 37.4; R_{LF} = 40.5; R_T = 42.9 and thus the **C_{RF} = 2054.3.**

This qualitative and quantitative analysis confirms the complexity of the issues that confront companies intending to close mines in this region, typified by:

- difficult climatic and topographic regions,
- communities expecting significant lifestyle improvements and opportunities
- political and social instability
- governments heavily reliant on the revenues from mining, and
- opposition from NGOs and others.

AN EMPIRICAL CLASSIFICATION

Based on the empirical evidence to date, the following classification table provides a guide to the relationship between the closure risk factor and the complexity of closure.

C_{RF}	**Closure Risk Rating**	**Typical Characteristics**	**Examples**
> 2000	Extreme	Environmentally and socially sensitive locations; subjected to past, extensive environmental abuse;	Large scale open cut mines in Pacific, Indonesia
1000 – 2000	Very high	Proximity to extremely sensitive areas eg world heritage; long established mining towns; sensitive commodities such as uranium, asbestos;	Arnhem land uranium mines; Butte; Broken Hill; Wittenoom blue asbestos;
500 – 1000	High	Large surface mines in proximity to settled areas; mines in developing countries; gold or other mines with acid mine drainage	Hunter Valley strip mines; Pine Creek geosyncline gold mines; Zambian copperbelt;

		potential; any mines where mine is only employer in local community;	
300 – 500	Moderate	Underground coal mines with pillar extraction; hard rock mines using caving methods; suspect crown pillars; gold mines in remote, semi-arid regions;	Lake Macquarie underground coal mines; Northparkes block cave mine;
< 300	Minor	Alluvial strip mines using chemical-free gravity treatment; underground coal mines with first workings only; clay quarry near regional centre – to be used as landfill or other purpose on closure; small extractive operations;	Lithgow coal mines; New England sapphire mines; Bexhill brick pit; Sand extraction in any capital or regional city;

Table 5: Relationship between CRF and complexity of mine closure

CONCLUSION

The closure risk model is a simple analytical technique that allows the decision maker to simplify what is often a complex mine closure process into sub components. This systematic approach ensures that critical factors in the closure process are not overlooked and allows the important issues to be highlighted.

The model can also be used to produce quantitative estimates of risk by weighting the issues to produce the Closure Risk Factor (C_{RF}). A comparison of closure risk factors from various sites will be particularly useful for the larger company with a stable of sites to allow appropriate resources to be dedicated to those sites with the highest risks. Correspondingly, a government department regulating numerous sites will find the tool useful in applying its limited resources for the best outcome. The technique will assist industry and government personnel to achieve the optimum closure outcome in the knowledge that all factors, and not just environmental factors, have been adequately considered.

It must be stressed that relying on a single number is not a panacea for decision makers. The real worth and the power of this management tool is in the analysis of all the issues that influence or are influenced by the mine closure process and the weighting of their relative importance. The analysis should not be the sole responsibility of an individual who is unlikely to have the necessary expertise in all closure issues, but ideally should be a team exercise. Once all the factors have been considered and weighted, then can appropriate resources and focus be given to those that present the highest risk.

The model has been derived empirically and its accuracy and therefore validity will continue to increase in proportion to the number of mines surveyed.

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